CLASSICAL CEPHEIDS: CHROMOSPHERIC HEATING AND FORMATION OF THE HELIUM SPECTRUM

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Semi-Annual Report, No. 4

For the period 16 February 1995 through 14 August 1995

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During the period covered by this report the results from our last paper on the ROSAT observations of ζ Gem (Sasselov & Sabbey 1994) became the basis for multi-wavelength comparison of energy distributions of Cepheid variables and nonvariable supergiants by Nancy Evans & Terry Teays (1995). They found that the non-radiative ultraviolet flux in the *IUE* data on nonvariable supergiants is nonexistent or much reduced in Cepheids. At the same time, the energy distributions at longer wavelengths are identical. The difference between X-ray fluxes of Cepheids and their non-variable counterparts, discovered by our ROSAT project is in the same sense and stronger.

We discussed this new developments in a poster at the IAU Colloquium No.155 last February. Our plans are to understand the physical connection between the UV and X-ray flux estimates and differences, by extending the Cepheid atmosphere modelling from last year by Sabbey, Sasselov *et al.* (1995).

During the period covered by this report, the PI was invited to made two presentations based on the findings from this project – a colloquium talk at the University of Toronto, Canada; and a poster paper at IAU Colloquium No. 155, on *Astrophysical Applications of Stellar Pulsation* in Cape Town, South Africa.

PAPERS:

1. "ROSAT Observations of Classical Cepheids: ζ Gem", by D. D. Sasselov & C. N. Sabbey, *Revista Mexicana de Astronomia y Astrofisica*, **29**, 215, 1994.

2. "On Spectral Line Formation and Measurement in Cepheids: Implications to Distance Determination", by C. N. Sabbey, D. D. Sasselov, M. S. Fieldus, J. B. Lester, K. A. Venn, & R. P. Butler, *Astrophysical Journal*, **446**, 250, 1995.

3. "X-ray Observations of ζ Gem with ROSAT", by D. D. Sasselov, in *Astrophysical Applications of Stellar Pulsation*, IAU Colloquium 155, eds. R. S. Stobie & P. Whitelock, 1995, in press.

Final Report

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Classical Cepheids are supergiants and bright giants of spectral classes F-K and they resemble in many respects non-variable stars in the same location of the HR diagram. Among the features Cepheids do not seem to share with their non-variable counterparts is coronal activity. Ten years ago the X-ray flux limits set by the *Einstein* Observatory for three Cepheids did not settle the question, because the upper limits were at the same level as X-ray fluxes observed in non-variable supergiants.

To look for an answer we used *ROSAT* for new deep pointed observations of the Cepheid ζ Gem (P=10 days, F7-G3 Ib). The Cepheid was observed on two separate dates in September and October 1992. All the X-ray data obtained by ROSAT for ζ Gem was received from Goddard Space Flight Center. Together with Chris Sabbey, a senior student at Harvard University, the data was fully reduced. With the help of Stephen Guimond of the CfA ROSAT Visitor Center, we managed to create a complete appended file from all exposures (from different dates). This enabled us to derive a new very low upper limit on the X-ray luminosity of the Cepheid.

The upper limits are approximately 5 times lower than previously observed. This means that the soft X-ray luminosity of ζ Gem is below $1.0 \times 10^{29} ergs^{-1}$. In terms of X-ray to bolometric luminosity, this means that the Cepheid is more than 80 times weaker than our Sun, and more than 20 times less luminous than Canopus (F0 Ib) and 11 Pup (F8 II) in X-rays.

We presented our results at the Symposium on "Stars, Gas, and Dust in the Galaxy", ed. A. Arellano-Ferro, Mexico City, August, 1993, and wrote a paper for the proceedings.

Photometric and spectroscopic observations of ζ Gem were obtained simultaneously to the ROSAT X-ray data. These were reduced and analysed during the second year covered by the grant. Model calculations with the improved X-ray illumination boundary condition were made – Sasselov & Lester (*Astrophys. Journal*, 423, 795, 1994). The reduced X-ray data obtained by ROSAT for ζ Gem was used to calculate detailed non-LTE radiation hydrodynamics models of its pulsating atmosphere. The results show that spectral line formation does not follow the kinematics of the gas flow, which has implications to distance determinations. A paper was written – Sabbey, Sasselov *et al.* (*Astrophys. Journal*, 446, 250, 1995).

During the period covered by this report the results from our last paper on the ROSAT observations of ζ Gem (Sasselov & Sabbey 1994) became the basis for multi-wavelength comparison of energy distributions of Cepheid variables and nonvariable supergiants by Nancy Evans & Terry Teays (1995). They found that the non-radiative ultraviolet flux in the *IUE* data on nonvariable supergiants is nonexistent or much reduced in Cepheids. At the same time, the energy distributions at longer wavelengths are identical. The difference between X-ray fluxes of Cepheids and their non-variable counterparts, discovered by our ROSAT project is in the same sense and stronger.

We discussed this new developments in a poster at the IAU Colloquium No.155 last February. Our plans are to understand the physical connection between the UV and X-ray flux estimates and differences, by extending the Cepheid atmosphere modelling from last year by Sabbey, Sasselov *et al.* (1995).

Our results seem to indicate that classical Cepheids do not have any hot plasma in their upper atmospheres. This imposes severe constraints on the sources of coronal heating in luminous cool stars. These sources seem to be inhibited by the global envelope pulsation, unlike the sources of chromospheric heating which are not affected.

During the period covered by this report, the PI was invited to make presentations and give colloquia talks based on the findings from this project – colloquia talks at the Institute d'Astrophysique, Paris; University of Oslo, Norway; Observatoire Haute Provence, France; University of Montpellier, France; Center for Astrophysics, Cambridge; and University of Toronto, Canada; and a poster paper at IAU Colloquium No. 155, on *Astrophysical Applications of Stellar Pulsation* in Cape Town, South Africa.

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